CFD ANALYSIS OF FLOW PATTERN IN ELECTROCHEMICAL MACHINING

A THESIS SUBMITTED IN PARTIAL FULFILMENT

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By

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CERTIFICATE

This is to certify that thesis entitled, "CFD ANALYSIS OF FLOW PATTERN IN ELECTROCHEMICAL MACHINING" submitted by Mr. SURESH SAIN in partial fulfillment of the requirements for the award of *Bachelor of Technology* Degree in Mechanical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

Date: 11th may, 2011

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Date: 11th may, 2011

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ABSTRACT:-

Electrochemical machining is the advanced machining method and it has been applied to many highly specialize field like aerospace and medical industries. But, in this technology still we have many problems to overcome such as electrolytic processing and disposal of metal hydroxide sludge etc.. Many of machine tools used in this machining method works in a pulsating mode. So besides these vibrations we can't get accuracy in the results. So to obtain the accurate results we have to overcome these problems, and CFD is considered to be the most powerful tool for that. But there is no such numerical method which can satisfactorily predict the flow. It is necessary to take into account that the unsteady character of electrolyte flow in the inter-electrode space. For this purpose orthogonal coordinate system it to introduce on the anode surface.

For the description of the electrolyte flow the system of the equation of preservation for mass of liquid and we have to find the solutions of different parameters used in this technology and also compare these quantities with the standard values. For these entire CFD analysis purpose one can use Gambit-Fluent software which can provide an overview about the machining parameters like, how they affect the process, which flow velocity is suitable for a particular value of current density.

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NOMENCLATURE

ϑ_m= Mass-averaged velocity

ρ_m= Mixture density

α_k= Volume fraction of phase k

n = no. of phases

F= Body force

μ_m= Viscosity of mixture

$\vartheta_{dr,k}$= Drift velocity for secondary phase k

k_{eff} = Effective conductivity

k_t= Turbulent thermal conductivity

G_b = Turbulent K.E. due to buoyancy

G_k = Turbulent K.E. due to mean velocity gradient

σ = Turbulent Prandtl no.

CHAPTER 1

INTRODUCTION

1.1 Overview of ECM process:-

It is very difficult to machine a high strength, heat-resistant material into complex shapes by conventional techniques, but such materials can be effectively machined by electrochemical machining (ECM) method. Therefore it stemmed the requirement of electrochemical machining process in many industries. ECM is an electrochemical process in which the work piece acts as an Anode and the tool acts as a Cathode. An electrolyte generally sodium chloride or sodium nitrate with a velocity of 5-50 m/s is supplied through the concentric hole in the cathode and it falls over the anode surface, a small gap of 0.05-0.8 mm is provided in between the two electrodes. When a small voltage of 5-30 V is applied across the inter electrode gap, a high current density of the order of 5-100 A/cm^2 is producing which results in dissolution of metal from anode (work-piece) electrochemically and gas generation occurs at cathode-tool electrode. Allowing the electrolyte to flow through the inter-electrode gap to remove the solid and gaseous products as well as the heat generated caused by the passes of current and electrochemical reactions. The rates of electrochemical dissolution depend strongly on the temperature. The energy losses in the gap are large but the heat can be removed by high flow of electrolyte and, thus, depends on the geometry. Accordingly the temperature at the anode surface is not exactly known, it can be in the range from 40 to 85 ^oC. The ECM method is quite effective and accurate to obtain a required shape of work-piece within a given tolerance on the shape and dimensions using the cathode-tool electrode with a shape which is geometrically close to the final shape of the work-piece.

1.2 Principal of ECM:-

ECM is the controlled removal of metal by anodic dissolution in an electrolytic cell in which the work piece is the anode and the tool is cathode. Electrochemical machining is developed on the principle of Faradays and Ohm. In this process, an electrolyte cell is formed by the anode (work-piece) and the cathode (tool) in the midst of a following electrolyte. The metal is removed by the controlled dissolution of the anode according to the well-known Faradays law of electrolysis. Fig1.1 shows two electrodes which are placed closely with a gap of about 0.5 mm and immersed in an electrolyte which is a solution of sodium chloride (common salt).

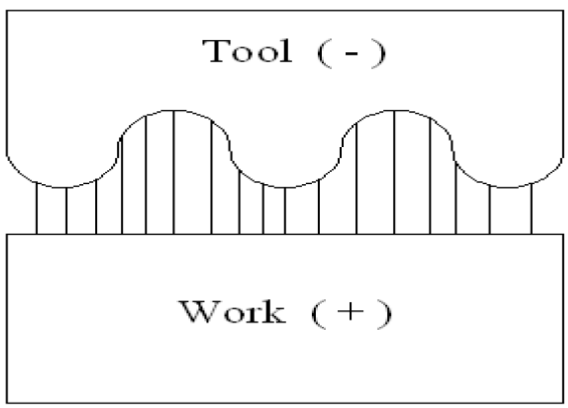

Figure 1. 1 Inter-electrode gap

The high current densities promote rapid generation of metal hydroxides and gas bubble in the small spacing between the electrodes. These become a barrier to the electrolyzing current after a few seconds. To maintain a continuous high density current, these products of machining must be continuously removed. This is achieved by circulating the electrolyte at a high velocity through the gap between the electrodes. It is also to be noted that the machining gap size increases as the metal is removed. The larger gap leads to a decrease in the metal removal rate.

Therefore to maintain a constant gap between the tool and work-piece, the cathode (tool) should be advanced towards the anode (work) at the same rate at which the metal is removed.

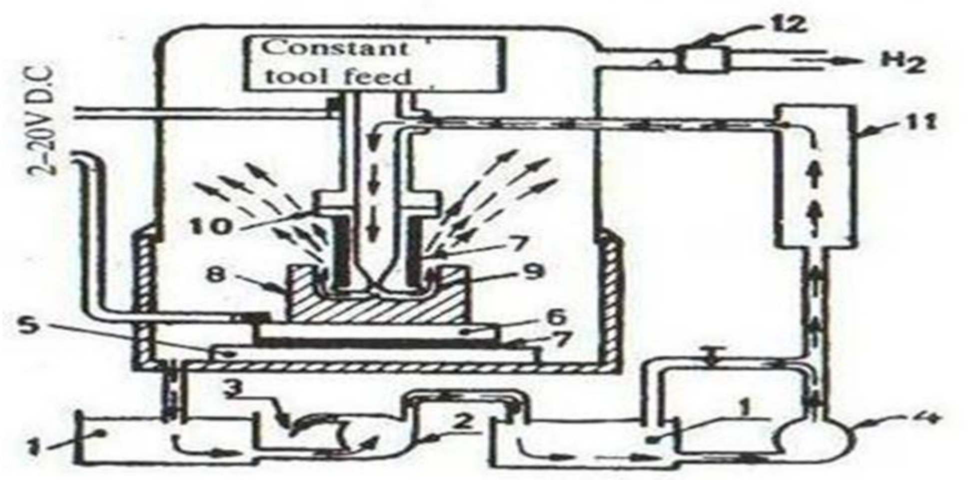

Figure 1. 2 Schematic diagram to show the electrolyte flow

ECM process is quite similar in concept to electrical discharge machining with a high current passed across its inter-electrode gap through the electrolyte, a material removal process having a negatively charged electrode (cathode-tool), conductive fluid (electrolyte), and a conductive work-piece (anode), however in ECM there is no tool wear. The ECM cutting tool is guided along the desired path very close to the work but it does not touch the piece. Unlike EDM however, no sparks are created.

1.3 Chemical reactions involves in ECM process:-

When a potential difference is applied across the inter-electrode gap, the water and electrolyte present in the gap undergo ionic dissociation as shown below,

$NaCl \leftrightarrow Na^{+} + Cl^{-}$

$H^{2}O \leftrightarrow H^{+} + (OH)^{-}$

Also the positive ions move towards the tool and negative ions move towards work-piece. Thus the hydrogen ions will take away electrons from the cathode (tool) and from hydrogen gas as:

$2H^{+} + 2e^{-} = H^{2}\uparrow$ at cathode

Similarly, iron from work-piece material, forms iron ion and it combines with hydroxyl ion to form sodium hydroxide as,

$Fe = Fe^{++} + 2e^{-}$

$Na^{+} + OH^{-} = NaOH$

In practice $FeCl_2$ and Fe $(OH)_2$ would form and get precipitated in the form of sludge. In this manner it can be noted that the work piece gets gradually machined and gets precipitated as the sludge. Moreover there is not coating on the tool, only hydrogen gas evolves at the tool.

REACTION AT ANODE:

$Fe \leftrightarrow Fe^{2+} + 2e^-$

$Fe^{2+} + 2Cl^- \leftrightarrow FeCl_2$

$Fe^{2+} + 2OH^- \leftrightarrow Fe(OH)_2$

$FeCl_2 + 2OH \leftrightarrow Fe(OH)_2 + 2Cl^-$

$2Cl^- \leftrightarrow Cl_2(g) + 2e^-$

$2FeCl_2 + Cl_2 \leftrightarrow 2FeCl_3$

$H^+ + Cl^- \leftrightarrow HCl$

$2Fe(OH)_2 + H_2O + O_2 \leftrightarrow 2Fe(OH)_3\downarrow$

$Fe(OH)_3 + 3HCl \leftrightarrow FeCl_3 + 3H_2O$

$FeCl_3 + 3 NaOH \leftrightarrow Fe(OH)_3\downarrow + 3NaCl$

REACTION AT CATHOD:

$Na^+ + e^- \leftrightarrow Na$

$Na + H_2O \leftrightarrow Na(OH) + H^+$

$2H^+ + 2e^- \leftrightarrow H_2\uparrow$

It shows that only hydrogen gas will evolve at cathode and there will be no deposition.

1.4 ECM machine parameters:-

1.4.1 Electrolyte:-

The electrolyte is very essential parameter for the electrolytic process to work. In ECM process the electrolyte is used to perform three main functions:-

1. It dissipates heat produced in the operation.

2. It carries the current between the tool and the work-piece.

3. It removes the products of machining from the cutting region.

For ECM process the electrolytes must have high electrical conductivity, low toxicity and low corrosiveness. The electrolyte is pumped at about 14 Kg/cm2 and at speed ranging from 5-50 m/s.

1.4.2 Servo system:-

The servo system controls the tool motion relative to the work piece to follow the desired path. It also controls the gap width within such a range that the discharge process can continue. If tool electrode moves too fast and touches the work piece, short circuit occurs. Short circuit contributes little to material removal because the voltage drop between electrodes is small and the current is limited by the generator. If tool electrode moves too slowly, the gap becomes too wide and electrical discharge never occurs. Another function of servo system is to retract the tool electrode when deterioration of gap condition is detected.

1.4.3 Temperature control:-

To avoid the variation in the conductivity, the temperature of the electrolyte in ECM process must keep constant. Lower the temperature of the electrolyte; lower be the rate of metal removal and higher value of temperature may lead to the vaporization of the electrolyte. Therefore temperature of electrolyte must be maintained between 30 to 80°C.

1.4.4 Pumps:-

Single or multi-stage centrifugal pumps are used on ECM equipment. A minimum flow rate 20 liters/min per 100 A. Electrolyzing current is generally required. A pressure of 5-30 kg/cm^2 meets most of the requirements of ECM application.

1.4.5 Tool feed rate:-

In ECM process, a gap of about 0.05 to 0.8 mm is maintained between tool and work piece. For smaller gap, the electrical resistance between the tool and work-piece is very less and hence the current is high and accordingly maximum metal is removed. The tool is fed in to the work depending upon the how fast the metal is to be removed. The movement of the tool slide is controlled by a hydraulic cylinder giving some range of feed rate.

1.4.6 Material removal rate:-

It is a function of feed rate which dictates the current passed between the work and the tool. As the tool advances towards work, gap decreases and current increases which increases more metal at a rate corresponding to tool advance. A stable spacing between tool and work is thus established.

1.4.7 Tool design:-

As no tool wear takes place in ECM process, so any good conductor can be satisfactory used as a tool material, but it must be designed strong enough to withstand the hydrostatic force, caused by electrolyte being forced at high speed through the inter-electrode gap. The tool is made hollow for drilling holes so that electrolyte can pass along the bore in tool.

1.5 Specifications of ECM:-

TABLE 1.1 ECM specifications:

Working gap	0.05-0.8 mm
Current density	5-100 A/cm^2
Voltage	5-30 V
Current	50-40,000 amp
Temperature	30-80 ^0C
Velocity	5-50 m/s
Inlet Pressure	0.15-3MPa
Outlet Pressure	0.1-0.3MPa
Feed Rate	0.1-20mm/min
Electrolyte Used	Brine solution, Sodium nitrate
Specific power consumption	$7w/mm^3/min$
Accuracy and surface finish	0.02 mm, 0.4µm
Application	Machining hard material
Limitation	High specific energy consumption
Mechanical properties	Stress free machining, reduce tool wear
Surface properties	No thermal damage

CHAPTER 2

LITERATURE SURVEY

2.1 Overview of ECM and CFD process:-

Evgueny I. Filatov [1] In this paper, for the simulation of electrolyte flow, the process of EC machining of a two-dimensional surface of a machine part is the focus of this investigation. The linear approximation for electrostatic field is assumed and also assumes that a part of a small volume is occupied by liquid and remaining volume is occupied by both air and hydrogen together. For the description of the electrolyte flow, the system of the equations of preservation for mass of liquid, mass of air and mass of hydrogen, as well as equations of preservation for energy and pulse of the whole mixture was taken.

J. Kozak [2] presented the physical and mathematical models on the basis of which the simulation process module in the computer-aided engineering system for ECM (CAE-ECM) has been developed. It is desirable for accuracy that the final shape of work-piece should be achieved under steady state of ECM conditions, determined by prescribing the characteristic equilibrium gap S_f , hydrodynamic parameters such as pressures at the inlet and outlet of the gap and properties of electrolyte. The mathematical model of the ECM process, referring to the formulated problem consists of a sequence of mutual conjugated partial models which describe in the gap: distribution of the local gap size S, distribution of the flow parameters such as the static pressure p and the velocity v, distribution of temperature T, distribution of the void fraction b (volumetric gas concentration) or the thickness layer with two phase flow (electrolyte and gas) h, distribution of the electrical conductivity k and the current density i.

J. Kozak et al. [3] presented a new variant of ECM a universal tool electrode of simple shape with complex, controlled kinematics along the work-piece is presented and a mathematical model and computer simulation results of ECM-CNC.

An appropriate electrolyte, such as aqueous Natrium chloride solution, is chosen so that when a small voltage of 10–15 V is applied between the electrodes, metal is dissolved electrochemically from the anode-workpiece, and gas generation occurs at the cathode-tool electrode. Allowing the electrolyte to flow through the inter-electrode gap, the solid and gaseous products, as well as the heat generated are rapidly removed.

M.M. Lohrengel et al. [4] illustrated that the work-pieces of steel and other metals are structured in neutral $NaNO_3$ solution by anodic dissolution at large current densities (about 100 A/cm^2) and high electrolyte flow rates (some m/s). Accordingly, an identification of the processes, the structure and the current distribution at the interface of the work-piece is critical. Since available simulation software for ECMM neglects details of the work-piece*/electrolyte interface and needs detailed information on rate determining processes, two new strategies are presented.

Huaiqian et al. [5] proposed a precise and ecofriendly micromachining technology for aerospace application called electrochemical machining in pure water (PW-ECM). On the basis of the principles of water dissociation, a series of test setups and tests are devised and performed under different conditions. These tests explain the need for technological conditions realizing PW-ECM, and further explore the technological principles. The results from the tests demonstrate a successful removal of electrolytic slime by means of ultrasonic vibration of the work piece.

B. Bhattacharyya et al. [6] this paper includes the analysis of the basic material removal mechanism in the ECDM process for the effective machining of non-conducting ceramic materials with enhanced machining rate and higher machining accuracy. The ECDM process is influenced by various process parameters such as the applied voltage; the inter-electrode gap, the temperature, concentration and type of electrolyte; the shape, size and material of the electrodes; and the nature of the power supply, etc.

T.R. Idrisov et al. [7] proposed a model of anode dissolution at the electrochemical machining by bipolar microsecond pulses at current densities up to 100 A/cm^2, taking into account the non-stationary nature of anode and cathode potentials installation during the pulse effect and a preliminary reverse polarity pulse influence on anode potential, as well as change of temperature and gas-filling of an electrolyte in inter-electrode space (IES).

Lyubimov et al. [8] illustrated the peculiarities of synthetic diamond wear in tools for electrochemical grinding are studied for the machining of metal–ceramic hard alloys. The influence of structure, mechanical characteristics of both diamond grains and hard alloys as well as the regimes of grinding on diamond wear are considered. Data of diamond consumption during electrochemical grinding are presented in comparison with the routine grinding process. Initiation and development and the mutual relation of various components of the diamond deterioration-cracking, abrasion, adhesion, diffusion and chemical wear at the electrochemical grinding – are discussed. Optimum regimes of hard alloy electrochemical grinding are recommended: working voltage 5–8 V; current density 20–60 A/cm2; normal component of grinding force 1.5–2.0 MPa; grinding speed 12–15 m/s.

Jerzy Kozaka et al. [9] presented a mathematical model, the results of computer simulation and experimental investigations of electrochemical machining with a spherical tool-electrode. Accuracy of computer simulation evaluated by differences between results of experimental tests and computer simulation depends on accuracy of a priori estimation of electrochemical machining coefficient, total over potential of electrode processes, electrical conductivity of electrolyte, etc.

2.2 Objective of the present work:-

The main objective of this paper is an attempt to find out the temperature and velocity distribution of the electrolyte by using **Fluent** software, and also determine how much inlet velocity is required corresponding to a particular value of current density so that the maximum temperature of the electrolyte shouldn't exceeds the boiling temperature of the electrolyte. And finally a graph showing a relationship between inlet velocity & current density and inlet velocity & maximum temperature is to be drawn.

CHAPTER 3

MATHEMATICAL MODELLING

In this chapter the governing equations for the FLUENT software used in modal analysis have been depicted. And it also has been presented the element selection, assumptions made and simulation procedure used in this analysis.

When the electrical current flows through a conductor, then according to Joule's heating effect the electrical energy is converted into thermal energy and produces heat. Also the electrical conductivity is temperature dependent and the internal heat generation depends on electrical current.

3.1 Governing equation:-

In present work, if boiling of electrolyte takes place, then there exist two phases a liquid and vapors, and these two phases interacting with each other everywhere in the computational domain. The motion of each phase is governed by their respective mass and momentum conservation equations.

Continuity equation:-

$$\frac{\partial}{\partial t}(\rho_m) + \nabla . (\rho_m \vec{v}_m) = 0 \qquad (1)$$

Where, $\vec{v}_m$ is the mass-averaged velocity

And ρ_m is the mixture density

$$\vec{v}_m = \frac{\sum_{k=1}^{n} \alpha_k \rho_k \vec{v}_k}{\rho_m} \qquad (2)$$

$$\rho_m = \sum_{k=1}^{n} \alpha_k \rho_k \tag{3}$$

Momentum equation:-

The total momentum can be obtained by summing individual momentum of both phases. It can be expressed as:-

$$\frac{\partial(\rho_m \vec{v}_m)}{\partial t} + \nabla . (\rho_m \vec{v}_m \vec{v}_m) =$$

$$-\nabla p + \nabla . [\mu_m (\nabla \vec{v}_m + \nabla \vec{v}_m^T)] + \rho_m \vec{g} + \vec{F} + \nabla . (\sum_{k=1}^{n} \alpha_k \rho_k \vec{v}_{dr,k} \vec{v}_{dr,k}) \tag{4}$$

Where, n is the number of phases, μ_m is the viscosity of the mixture and F is a body force, $\vec{v}_{dr,k}$ is the drift velocity for secondary phase k.

Energy equation:-

$$\frac{\partial}{\partial t} \sum_{k=1}^{n} (\alpha_k \rho_k E_k) + \nabla . \sum_{k=1}^{n} (\alpha_k \vec{v}_k (\rho_k E_k + p) = \nabla . \left(K_{eff} \nabla T\right) + S_E \tag{5}$$

Where, K_t is the turbulent thermal conductivity (electrolyte),

k_{eff} is the effective conductivity ($\sum \alpha_k$ (k_k + k_t))

The energy transferred due to conduction is represented by the first term on the right hand side, where S_E includes any other volumetric heat sources.

Turbulence kinetic energy:-

The turbulence kinetic energy and its rate of dissipation can be obtained by solving the given transport equation:

$$\frac{\partial}{\partial t}(\rho k) \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_i}{\sigma_k}\right) \frac{\partial k}{\partial x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \tag{6}$$

And,

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} + S_\varepsilon \qquad (7)$$

Where, in these equations, G_K represents the generation of kinetic energy due to mean velocity gradient, Y_M represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate and G_b is the generation of turbulence kinetic energy due to buoyancy.

σ_k and σ_ε are the turbulent Prandtl numbers for k and ε respectively, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ are constants, .

S_k and S_ε are user-defined source terms.

3.2 Assumptions:-

1. In present analysis, the heat is generated in the inter-electrode gap only.
2. The domain is considered as axis-symmetric.
3. The channel through which electrolyte flows is considered to be a uniform cylinder
4. It is considered that the height of the electrode is much larger than the size of inter-electrode gap and the outer wall of the cylinder is considered to be adiabatic.
5. The current and voltage is kept constant throughout the analysis.
6. The material properties of both the electrodes will not change with temperature, but they will change for electrolyte.
7. The tool and work-piece are homogeneous and isotropic.
8. In the inter-electrode gap, there is a partial conversion of electrical energy into thermal energy by joule’s heating effect.

3.3 Simulation condition and procedure:-

For the ECM process, a tool, a work-piece and an electrolyte solution is required. So, in ECM process, copper is widely used as a tool, to machine an Iron work-piece in a brine solution (sodium chloride sol).

The flow and thermal analysis was performed when the flow parameters such as inlet velocity of flow, density & viscosity of the electrolyte and material properties such as density, thermal conductivity and specific heat for the copper and iron were provided. The heat generated per unit volume of the inter-electrode gap was dependent on the current density and temperature (as the electrical conductivity of electrolyte was temperature dependent). Because of heating, the temperature of the electrolyte is increased so that heat transferred through the walls of electrodes by the conduction process.

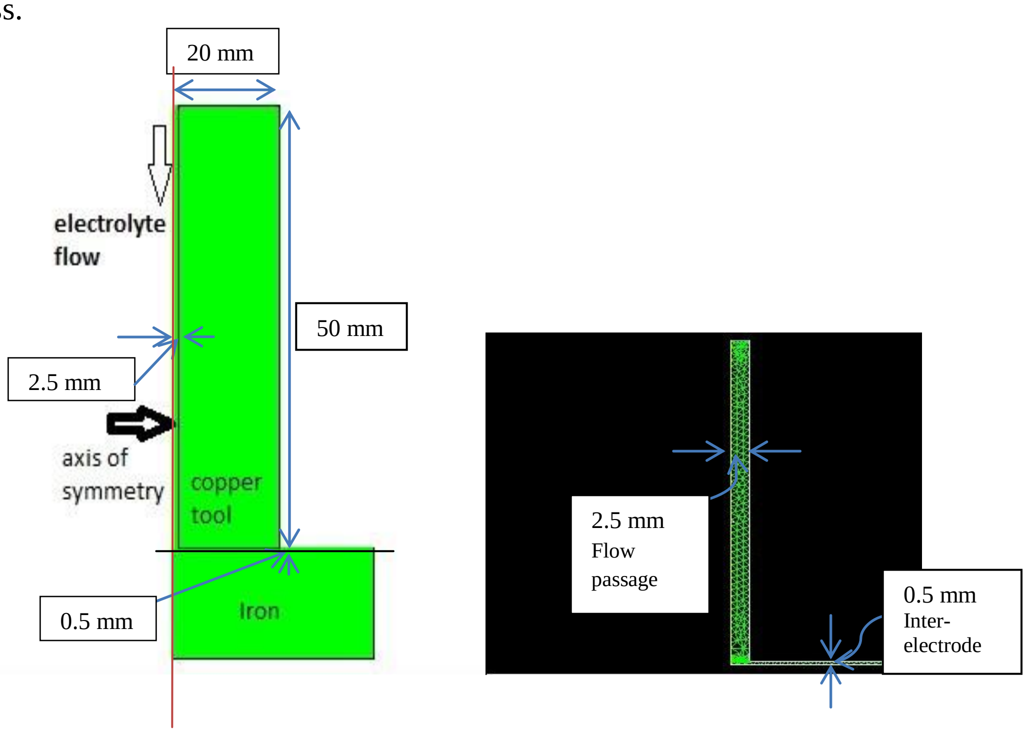

Figure 3. 1 Physical model for CFD analysis

3.3.1 Element type:

For CFD analysis by Fluent software, the model was first prepared and meshed in the Gambit and a mesh file was generated which is then reopened in fluent for the analysis where the element type and the boundary conditions were applied.

Table 3.1 the element type used in the analysis

Element	**Element Type**
Brine Solution	Fluid
Copper	Solid
Iron	Solid

3.3.2 Material properties and applied boundary condition:

For the analysis the material properties for the tool, work-piece and electrolyte are to be given as input. Also, based on governing equations the temperature and inlet velocity and the heat generation rate in the gap were given as loading variables.

Table 3.2 The material properties for copper, Iron and Electrolyte used in the analysis.

Material Property	Electrolyte	Copper	Iron
Density (Kg/m3)	1050	8940	7860
Conductivity (W/m/K)	0.6	401	80
Specific Heat (J/Kg/K)	3760	390	460
Viscosity (Kg/m/s)	0.001	-	-

Heat transfer coefficient through the walls of tool and work-piece = 1000 $W/m^2.K$

The inlet velocity of electrolyte flow is assumed from the range of 5 – 50 m/s.

Thermal boundary condition:

The outer surface of the tool-electrode was assumed to be adiabatic, also the inlet temperature of the electrolyte was considered to be 27 ^{0}C.

Electrical boundary condition:

A voltage of 10V and a current 100 amp were applied across the two electrodes.

The current density can be taken from the range of 5 – 30 A/cm^2 .

The pressure outlet boundary condition:

Gauge pressure= 0 Pascal

The heat generated in the gap is introduced by an UDF (user defined function).

After applying boundary conditions the solution was carried out and the temperature, velocity and pressure profiles were obtained.

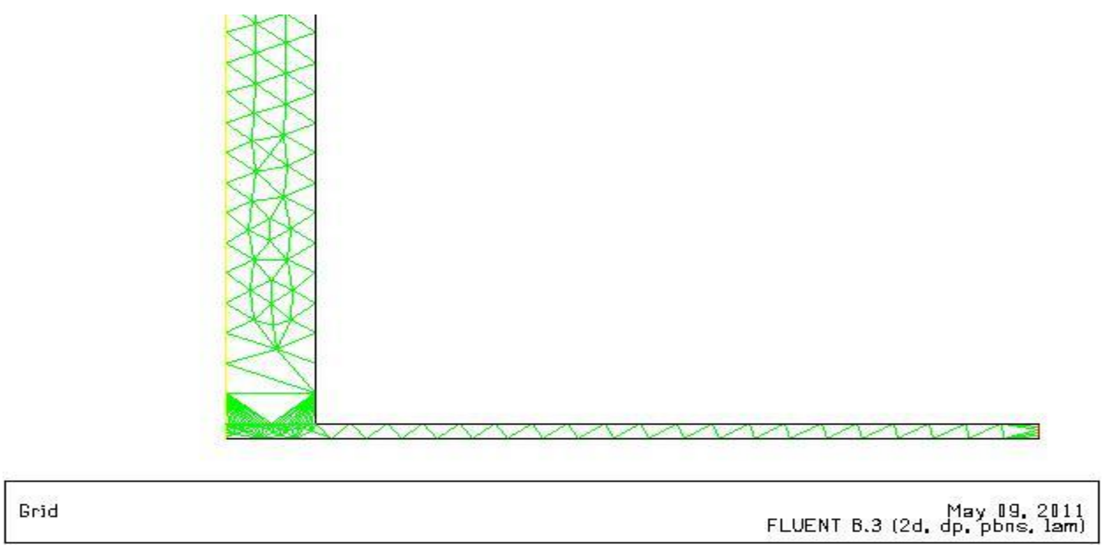

Figure 3. 2 Elements after meshing

CHAPTER 4

RESULT AND DISCUSSION

4.1 Temperature, Inlet Velocity and Pressure profiles:

The temperature, velocity and pressure profile were obtained for the different values of the current density and the corresponding inlet velocity during the analysis.

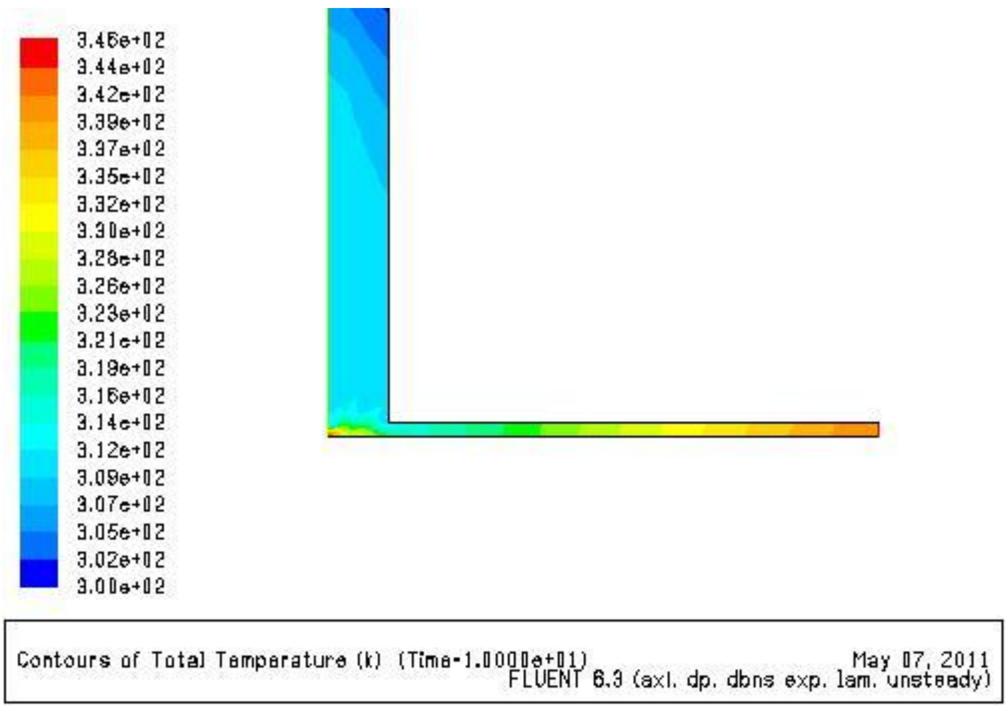

Figure 4. 1 Temperature profile for current density=5 A/cm2 and inlet velocity=5 m/s

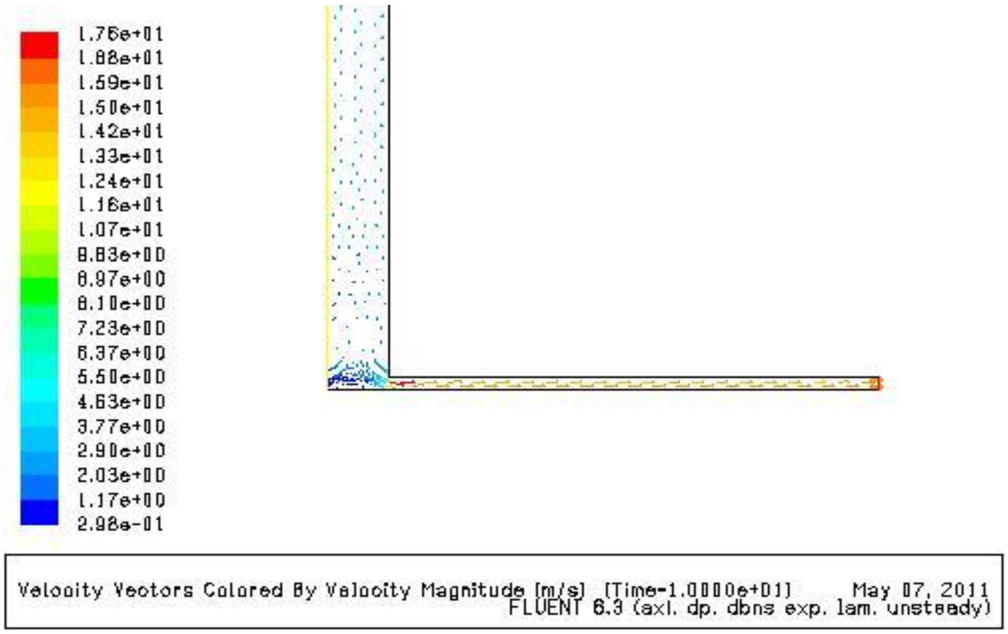

Figure 4. 2 Velocity profile for current density=5 A/cm2 and Inlet velocity=5 m/s

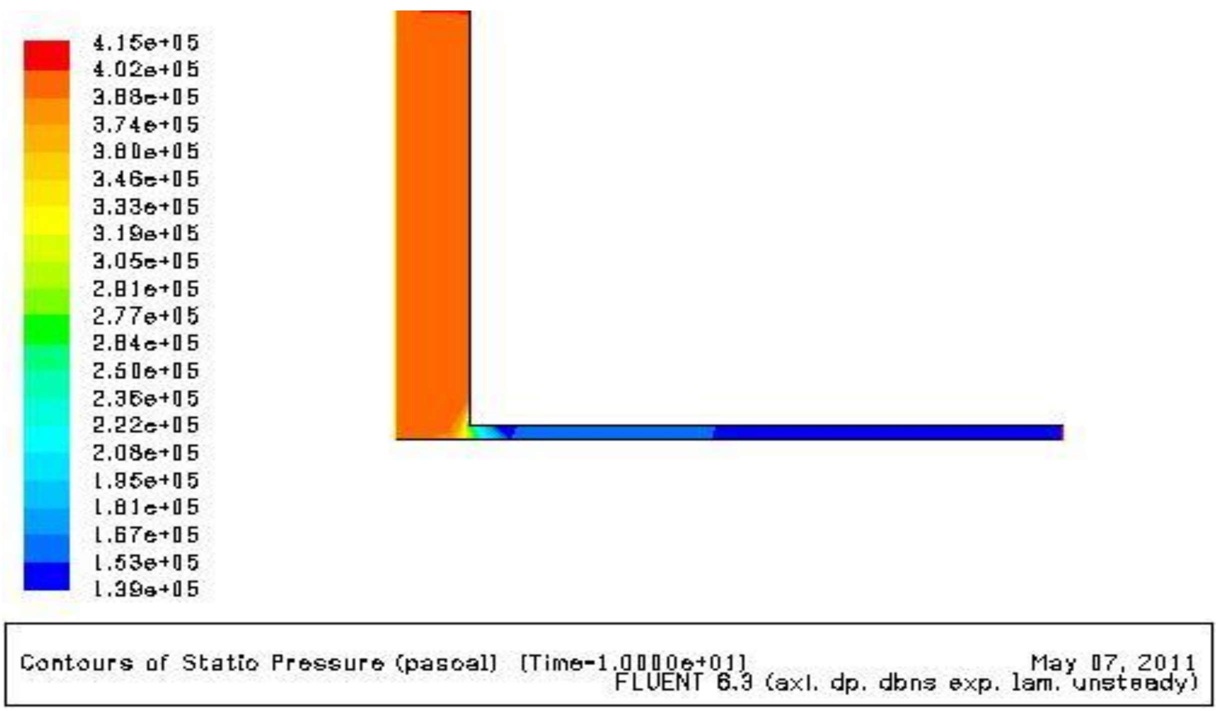

Figure 4. 3 Pressure profile for current density=5 A/cm2 and Inlet Velocity=5 m/s

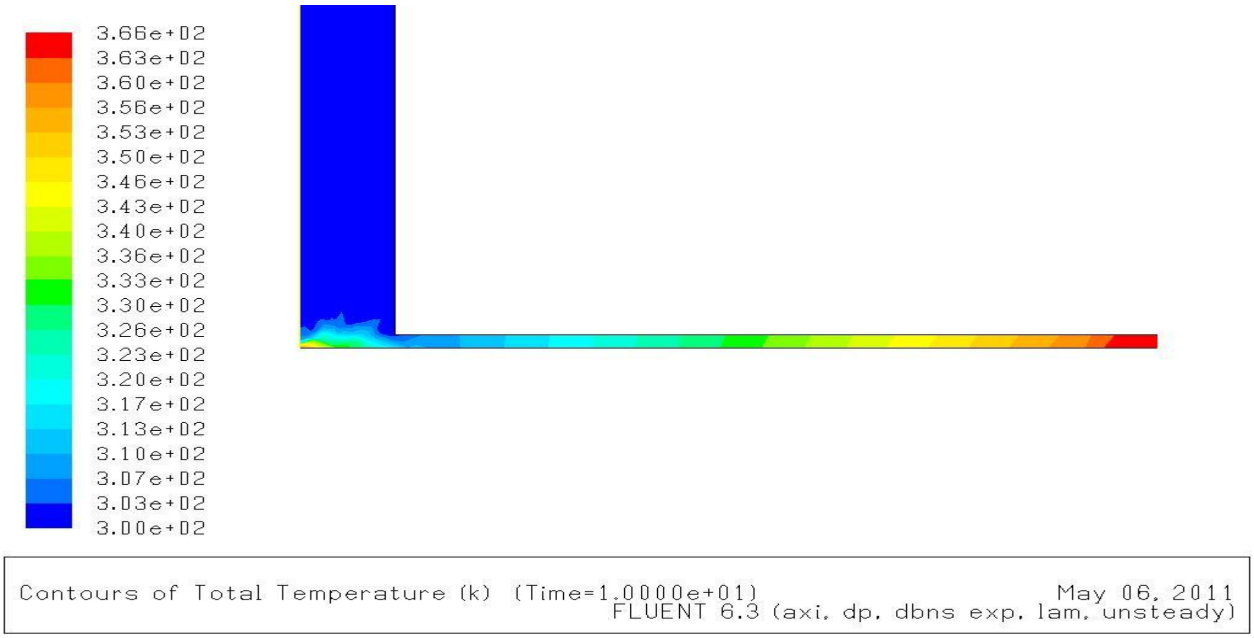

Figure 4. 4 Temperature profile for current density=10 A/cm2 and Inlet Velocity=15 m/s

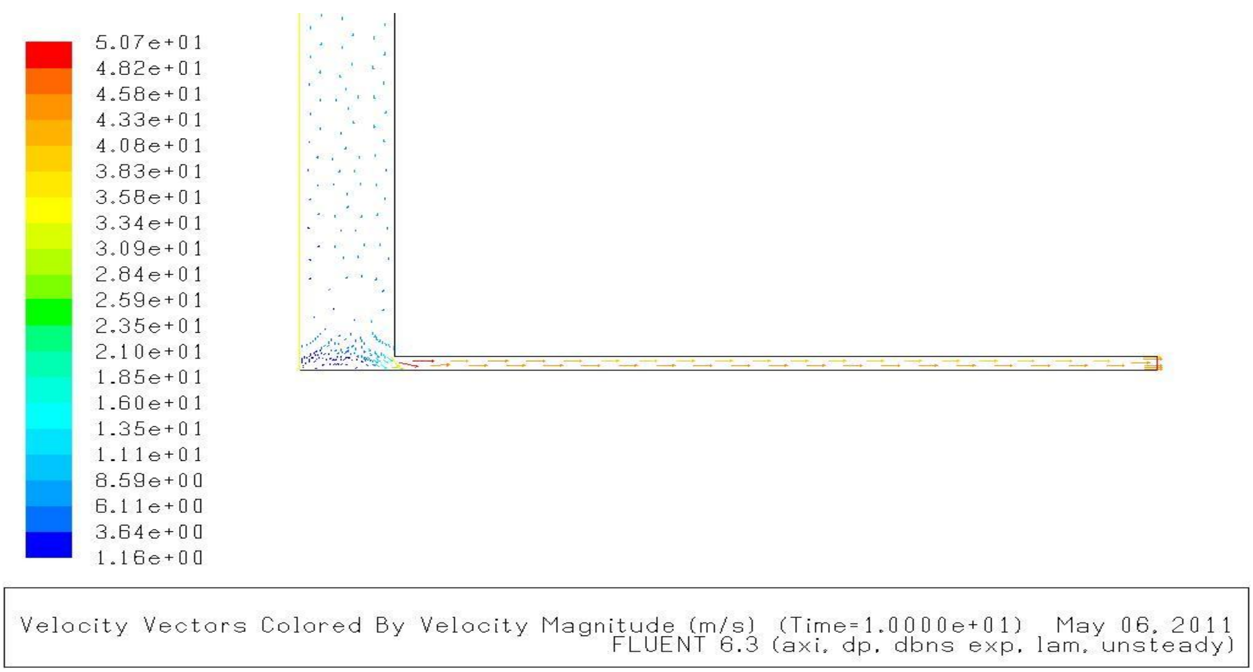

Figure 4. 5 Velocity profile for current density=10 A/cm2 and Inlet Velocity=15 m/s

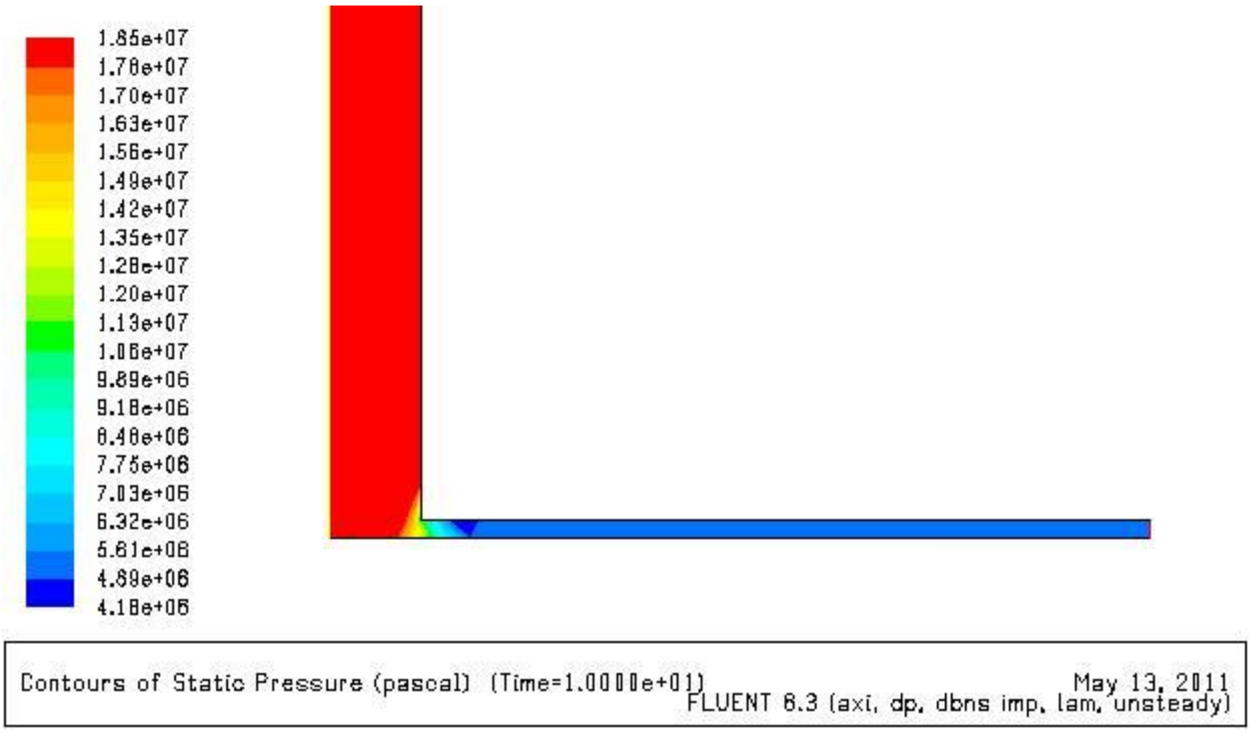

Figure 4. 6 Pressure profile for current density=10 A/cm2 and Inlet Velocity=15 m/s

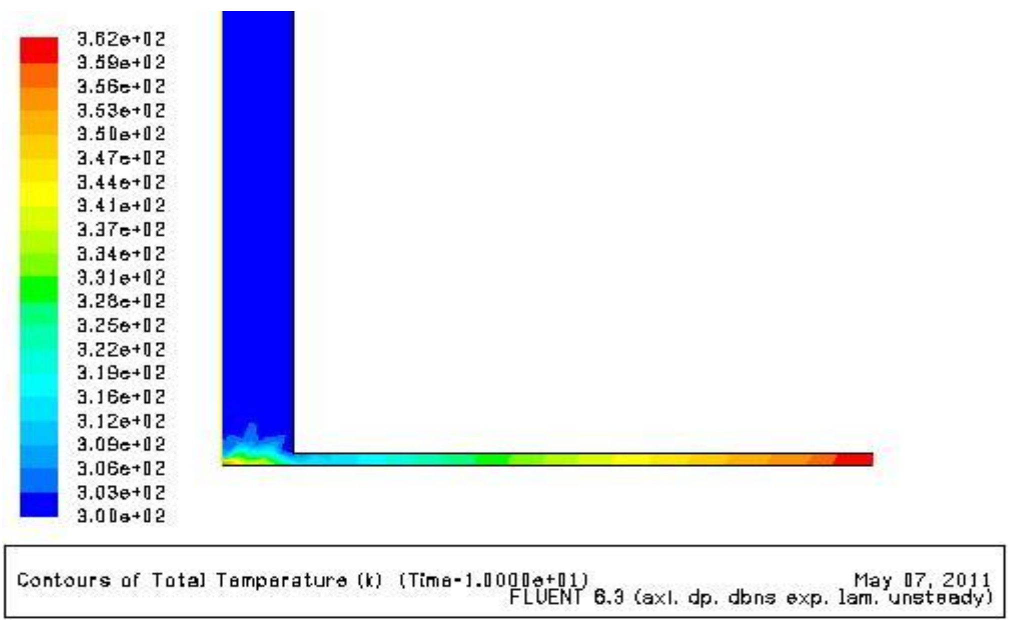

Figure 4. 7 Temperature profile for current density=15 A/cm2 and Inlet Velocity=22 m/s

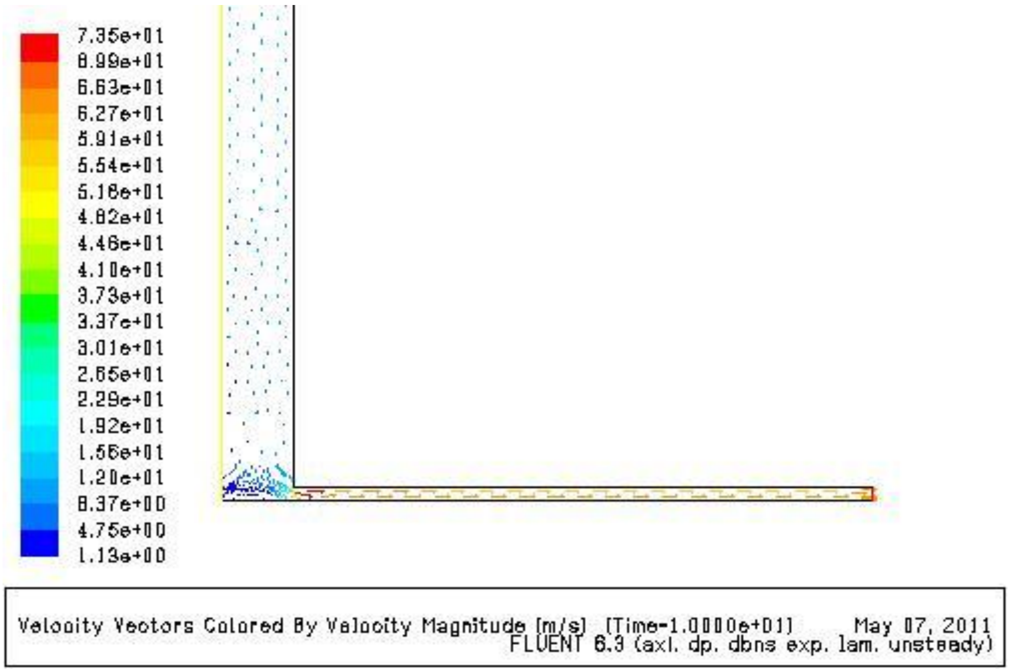

Figure 4. 8 Velocity profile for current density=15 A/cm2 and Inlet Velocity=22 m/s

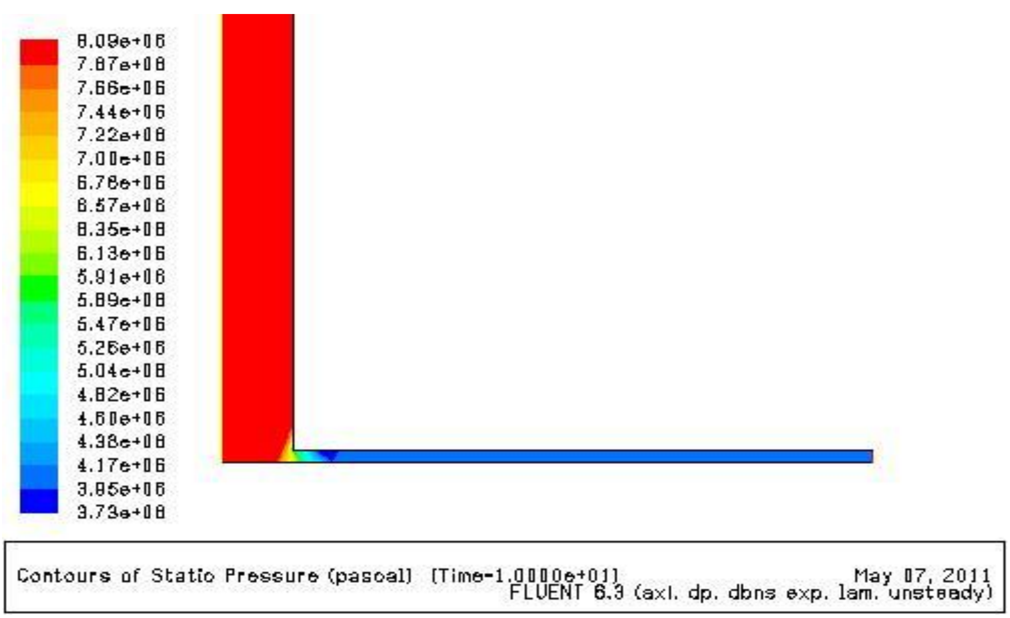

Figure 4. 9 Pressure profile for current density=15 A/cm2 and Inlet Velocity=22 m/s

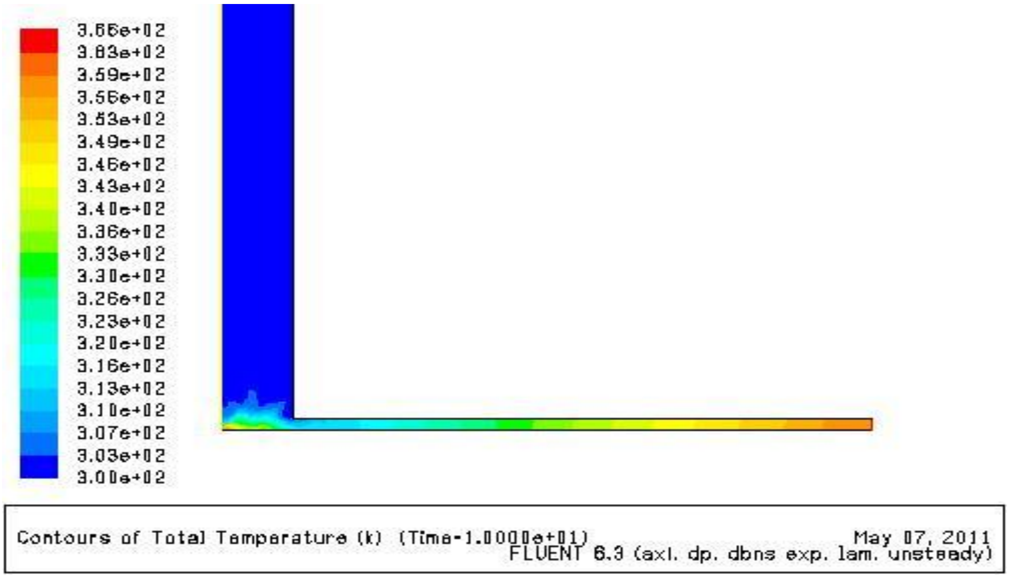

Figure 4. 10 Temperature profile for Current density=20 A/cm2 and Velocity=35 m/s

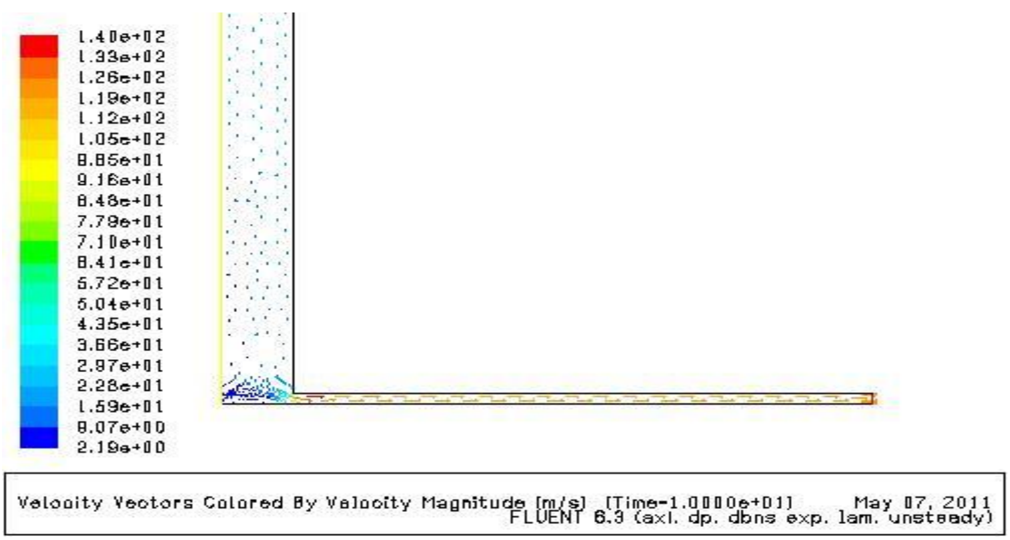

Figure 4. 11 Velocity profile for Current density=20 A/cm2 and Velocity=35 m/s

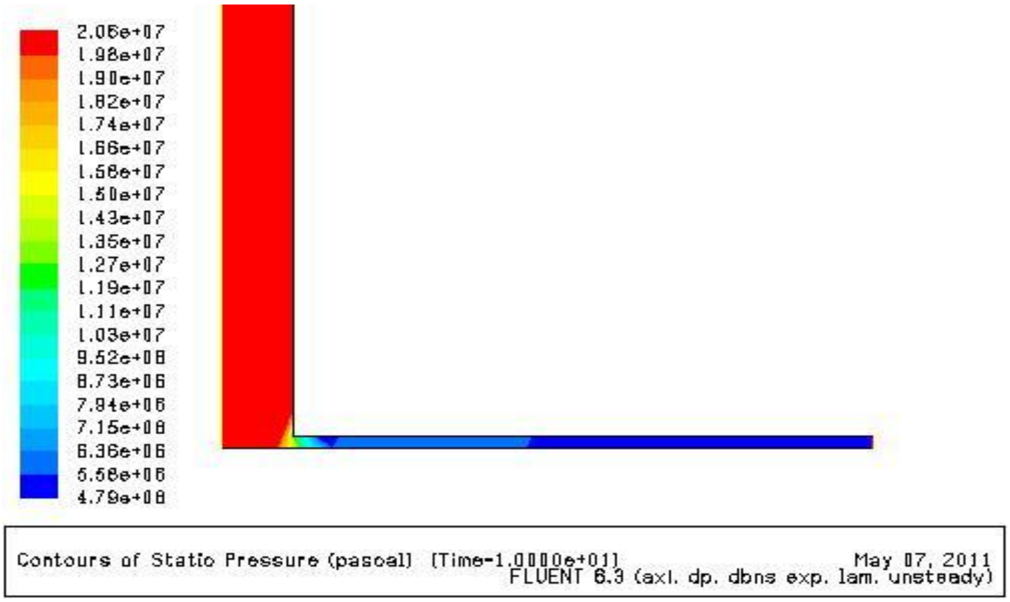

Figure 4. 12 Pressure profile for Current density=20 A/cm2 and Velocity=35 m/s

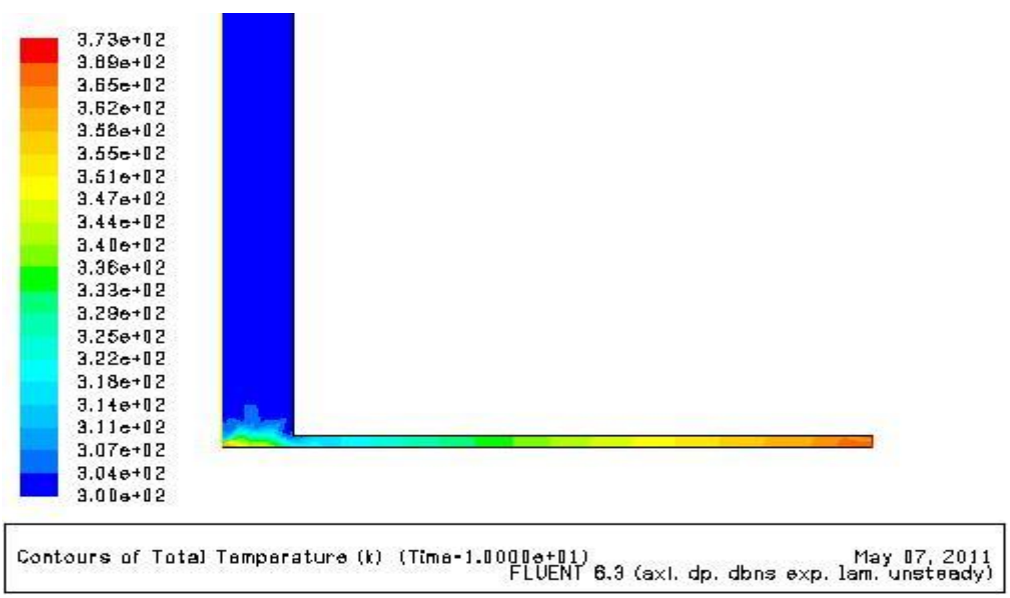

Figure 4. 13 Temperature profile for Current density=25 A/cm2 and Velocity=44 m/s

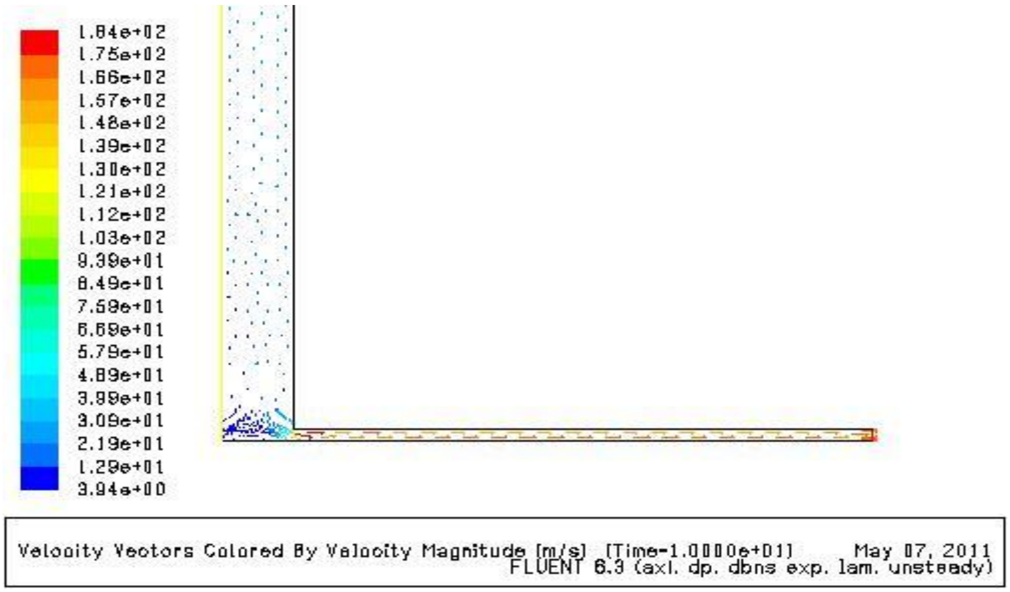

Figure 4. 14 Velocity profile for Current density=25 A/cm2 and Velocity=44 m/s

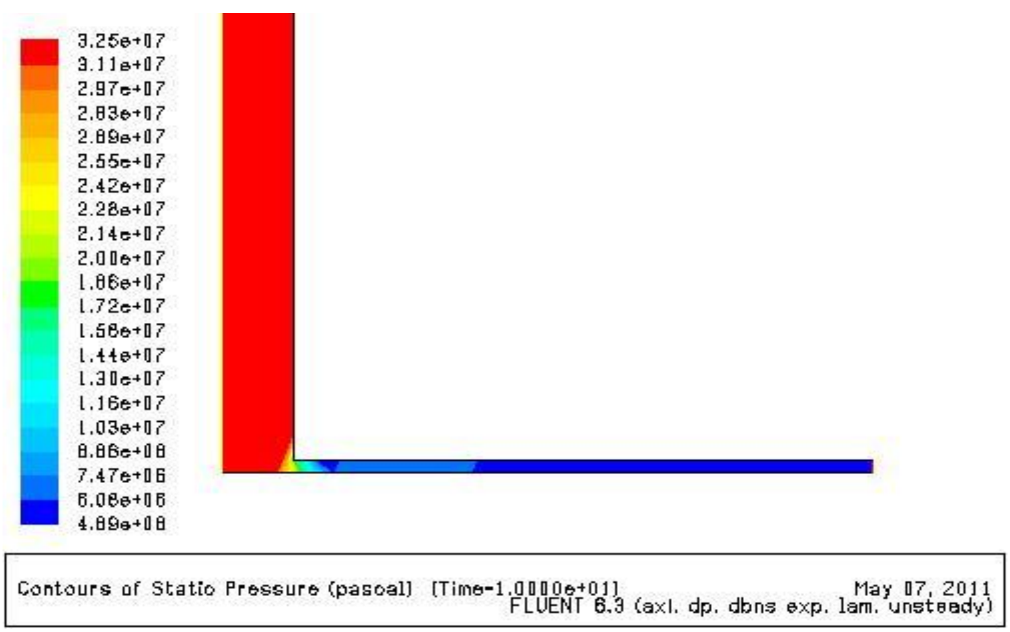

Figure 4. 15 Pressure profile for Current density=25 A/cm2 and Velocity=44 m/s

The above analysis shows that how the outlet temperature, velocity and pressure of the electrolyte varies with due course of time during the machining operation. During the machining, the heat was generated in the inter-electrode gap which results in increase in electrolyte temperature, but simultaneously the heat was dissipated through the walls of tool and the work-piece by the process of conduction and also by cooling action of electrolyte. So, that final temperature of the electrolyte couldn’t reach very high. But this condition was achieved for a particular value of inlet velocity corresponding to a current density.

4.2 Graphical Solution:

In present work different inlet velocities were obtained for different values of current density, so a relation can be establish between them by plotting a graph. Also, for a particular value of current density, the dependency of the maximum temperature reached on inlet velocity can be shown by plotting a graph between inlet velocity & maximum temperature.

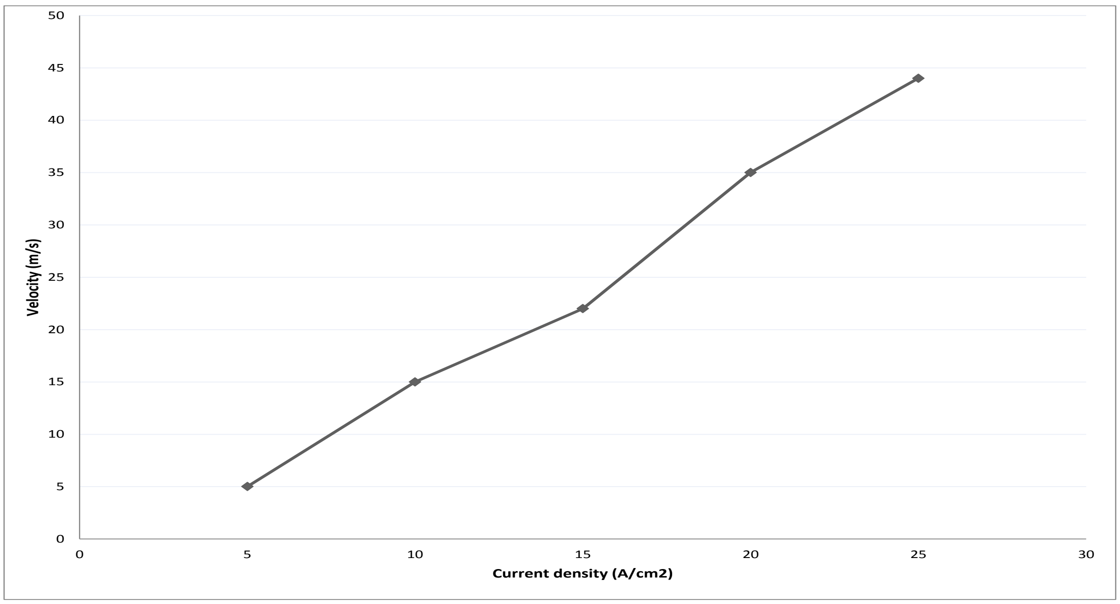

Figure 4. 16 Graph between current density v/s inlet flow velocity

The above graph explains that, as the current density increases the inlet velocity also increases, so that the outlet temperature shouldn’t exceeds the boiling temperature of the electrolyte and hence boiling of electrolyte didn’t took place.

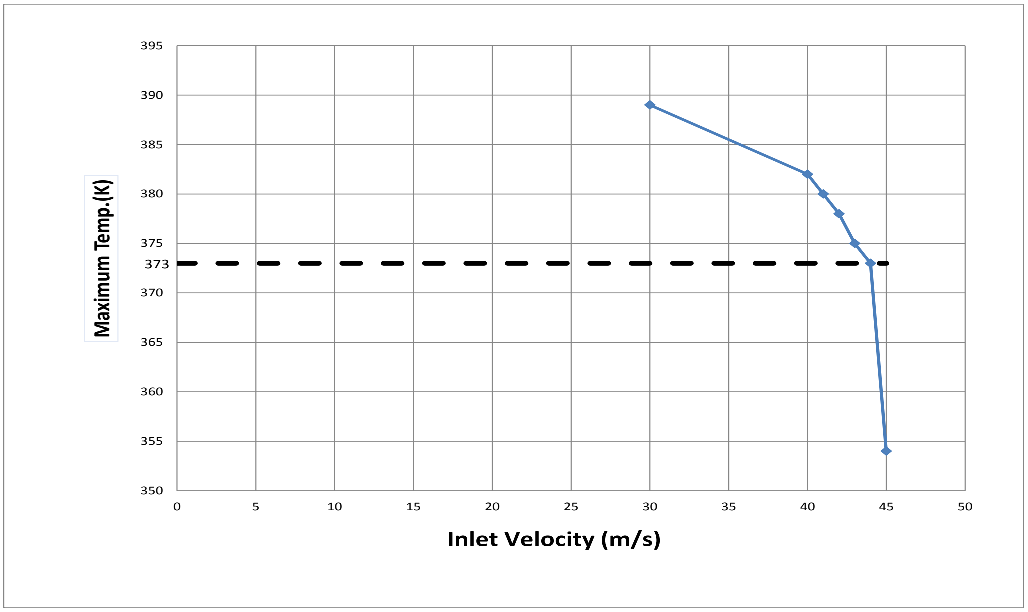

Figure 4. 17 Graph between inlet flow velocity and maximum temperature

The above graph explains that during the analysis, for a particular value of current density, the maximum temperature of electrolyte decreases with increase in temperature.

In present work this graph was plotted for a current density of 25 A/cm^2, and the inlet velocity ranges from 30 – 45 m/s. so that the maximum outlet temperature lies in a range of 350 – 389 ^0C.

During the analysis the outlet temperature of the electrolyte shouldn't reach its boiling point.

CHAPTER 5

CONCLUSION

In present work, since there is electrical energy source, so according to Joule’s heating effect, the heat is generated in the process, and hence the electrolyte temperature rises. This analysis predict the maximum temperature reached and also predict that the inlet flow velocity required for the process corresponding to a particular value of current density, so that boiling of electrolyte shouldn’t take place.

The main conclusions are:

1. The inlet flow velocity increases with increasing current density.
2. The maximum temperature of the electrolyte decreases with the increase in inlet velocity. The maximum outlet temperature decreases rapidly but for a certain range of velocity the change in temperature is not abrupt. For the higher value of inlet velocity the decrease in temperature is abrupt.
3. The flow velocity decreases when electrolyte moves towards the work-piece and it increases at the outlet.
4. The pressure is maximum at the inlet and minimum in the inter-electrode gap.
5. The 2D axisymmetric CFD analysis of flow using Fluent can be solved easily and it takes few seconds only.

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APPENDIX:-

User Define Function (UDF) to define the heat generation:

```
 #include"udf.h"
DEFINE_SOURCE(heatgeneration,c,t,dS,eqn)
{
real temp;
real source;
temp=C_T(c,t);
source=(j)2/{20(0.02*temp-5.)};
return(source);
}
```

Where, j is the current density.

APPENDIX:-

Program in FLUENT 6.3